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Volcanic Activity and Climatic Changes

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Since before the time of Aristotle, it has been known that climatic variation is in part a function of solar radiation intensity as it varies with latitude. In the last two centuries the idea has also emerged that climatic variation in time

Summary. Radiocarbon dates of volcanic activity suggest variations that appear to be related to climatic changes. Historical eruption records also show variations on the scale of years to centuries. These records can be combined with simple climatic models to estimate the impact of various volcanic activity levels. From this analysis it appears that climatic prediction in the range of 2 years to many decades requires broad-scale volcanic activity prediction. Statistical analysis of the volcanic record suggests that some predictability is possible.

might be related to variations in ground-level solar intensity (*1*). These variations could be due to either changes in the solar output or changes in the transparency of the atmosphere. Indeed, the more successful simulations of the course of hemispheric or zonal temperatures over the past century have been based on the assumption that the transparency of the cloudless atmosphere has varied—specifically, as related to this article, in response to variations of volcanically produced turbidity (*2*).

In part, these models help distinguish between variations of direct-beam solar radiation observed at the surface and variations produced by volcanic debris changing the atmospheric transparency. For example, the sensitivity of the hemispheric mean surface temperature to a 1 percent change in the solar constant is about 1.2 to 2.0 K (*2*). Since the measured values of direct solar radiation decreased about 5 percent during the period 1945 to 1975 (*3*), the surface mean temperature should have decreased 6 to 10 K during this time if only the solar constant varied (*4*). This is clearly much larger than the 0.3 K or so that was observed (*5*). On the other hand, if the turbidity of the atmosphere varied enough to reduce the direct beam at the surface by 5 percent, the surface mean temperature should have decreased by about 0.85 K, all other factors being ignored. This is because increased turbidity increases the diffuse radiation almost as much as it decreases the direct beam. Correcting this value for the effect of increasing carbon dioxide (about 12 parts per million), which gives a temperature increase of about 0.30 to 0.35 K (*6*), results in a calculated decrease in hemispheric mean surface temperature of 0.50 to 0.55 K. This is much closer to the observed decrease than the value obtained with the assumption of decreased solar constant. If we also take into account the lag produced by heat storage in the oceans, the match is very close.

The reasoning above with the aid of a physical model indicates that it will be necessary to estimate future levels of

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volcanic activity if we are to estimate climatic conditions for the coming few decades or for a century. In this article we will consider some aspects of past volcanic activity levels for further evidence of relationships with climate and hints of predictive properties such as trends and periodicities.

The Historic Volcanic Record

If the decline of atmospheric transparency since around 1945 is to be ascribed to increased volcanic activity, one should be able to find data that support the supposition. Two such sets of data are displayed in Fig. 1. The upper curve was constructed after a careful reanalysis of data on direct-beam radiation obtained by pyrheliometer and actinometer at 42 sites between 20° and 65°N. This is essentially the entire body of such data in the literature. The observations were converted to optical depths with a simple wavelength-integrated form of Beer's law over the visible range of wavelengths, removing differences in air mass, altitude, scaling factors, and time of year (*7*). These individual values were then combined into a time series of annual means, which were representative of the year-to-year variations in the total optical depth of the Northern Hemisphere. The upper curve in Fig. 1 is the residual optical depth attributable to aerosols after removal of the part due to clean air, water vapor, ozone, and so on (approximately 0.212 for the Northern Hemisphere). A method similar to the one used by Pivovarova (*3*) and others (*8*) was not used in this study, because it contains the implicit assumption that the long-term means for each station—regardless of the length of record, when in time the record occurred, and the background environment—are the same as the overall hemispheric mean. For an inhomogeneous data set this assumption biases the time series in such a way that long-term variations or low-frequency fluctuations are artificially suppressed. Since the beam radiation measurements are absolute, the assumption of equal means is not necessary and leads to erroneous results.

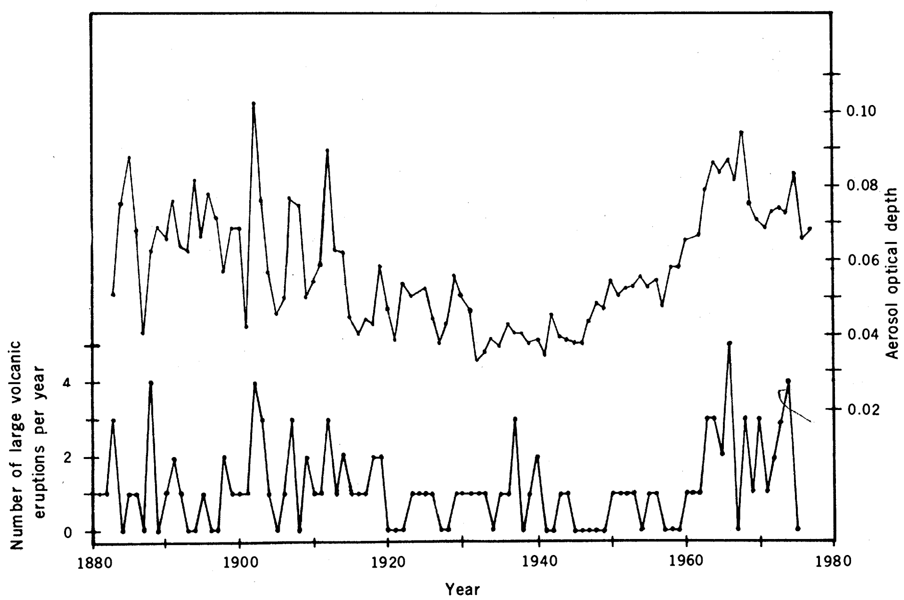

Fig. 1. Mean annual aerosol optical depth, based on 42 stations between 20° and 65°N (upper curve) and number of Northern Hemisphere volcanic eruptions of large magnitude per year (lower curve).

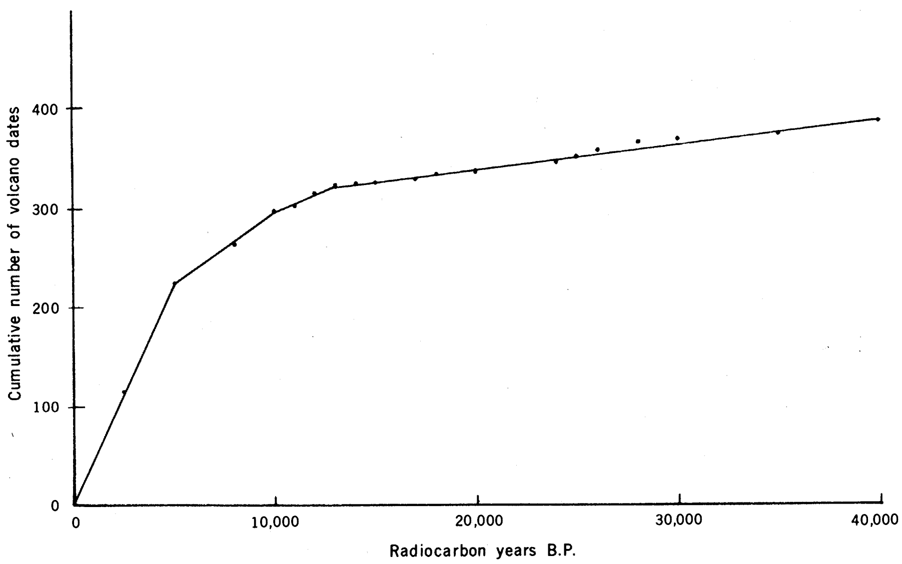

Fig. 2. Cumulative numbers of dated volcanic events counting backward to 40,000 B.P. Not all points are plotted.

The lower curve in Fig. 1 is drawn from the listing of about 6000 historically recorded eruptions in the files of the Center for Climatic Research at the University of Wisconsin, Madison. This is approximately ten times the number of eruptions in the Lamb chronology (*9*), which has been used by many authors to assess climate-volcano interactions (*10, 11*). The numbers used for Fig. 1 were for eruptions reported as being of great magnitude, but it should be noted that far more eruptions of all magnitudes were recorded during the early years of this century and the last decade than during the period 1925 to 1955. Indeed, the course of volcanic activity in this century is the inverse of the well-known course of hemispheric mean temperature. From 1945 to 1970, the annual eruption numbers roughly doubled from 16 to 18 per year to 37 to 40 per year. During the same interval, the aerosol optical depth also roughly doubled. This is in good agreement with the observations of Hammer (*12*), who reported a doubling in the amount of nonorganic impurities deposited on the Greenland Ice Sheet between times of low and high volcanic activity based on ice core analysis for the past 300 years.

Preliminary analysis of the variance spectra of eruption numbers, broken down by tectonic region, shows significantly more variance at certain frequencies than would be expected by chance. More than half of these significant frequencies are related to earth tides. If this result is confirmed by further study, some predictability of general levels of volcanic activity might be achieved.

The Radiocarbon-Dated Volcanic Record

An initial attempt to extend the history of volcanic activity back beyond the limit of written observations may be made by treating the sum of all published radiocarbon dates that refer to volcanic eruptions as a single time series (*13*). There are serious problems with this approach, but the results are quite suggestive.

Some of the problems with this series of dates are that (i) the older eruptions are underrepresented because more potential dating sites have been eroded away or buried; (ii) some volcanoes, studied intensively with adequate dating budgets, may be overrepresented; (iii) the sample may be totally inadequate and certainly does not represent even 1 percent of the volcanic events (*14*); and (iv) the dating errors increase with age, and the length of a radiocarbon century varies compared to calendar centuries.

Bearing these problems in mind, let us first examine the general variation of sampling as a function of time by plotting the cumulative numbers of dated Northern Hemisphere events as a function of time, counting back from the present (Fig. 2). The count per millennium decreases with increasing age, as indicated by the flattening slope of the curve. Figure 2 must be regarded primarily as a description of the sampling bias.

For the last 10,000 years the curve appears to consist of straight-line segments, and there is a rather sudden increase in the general level of volcanic activity at about 4800 to 4900 years before present (B.P.), very nearly at the end of what has been called the climatic optimum or Atlantic episode of European pollen chronology.

Assuming that the general slope of Fig. 2 represents the expected value due to the sampling bias, we can plot the ratio of the observed number of dated events per century to the expected number to obtain a first estimate of shorter times of enhanced activity or quiescence (Fig. 3). The last several centuries will, of course, be underrepresented because investigators will not waste the cost of a radiocarbon date on obviously recent eruptions, many of which are of known calendar date.

The striking features of Fig. 3 (remembering the difference between radiocarbon and calendar dates) are the peaks of activity about the time of the Cochrane ice advance or stillstand (around 8300 to 8500 B.P.), the large peak just preceding the long failure of the monsoon in northwestern India (around 3700 B.P.) (*15*), and the two large peaks at 1200 and 600 B.P. Correction to a calendar date shifts the 600 B.P. date later to mark the onset of the "Little Ice Age." The decline following the 600 B.P. peak is probably less dramatic than it appears because of the underrepresentation of historically dated eruptions. The peaks mentioned almost entirely represent activity north of 30°N.

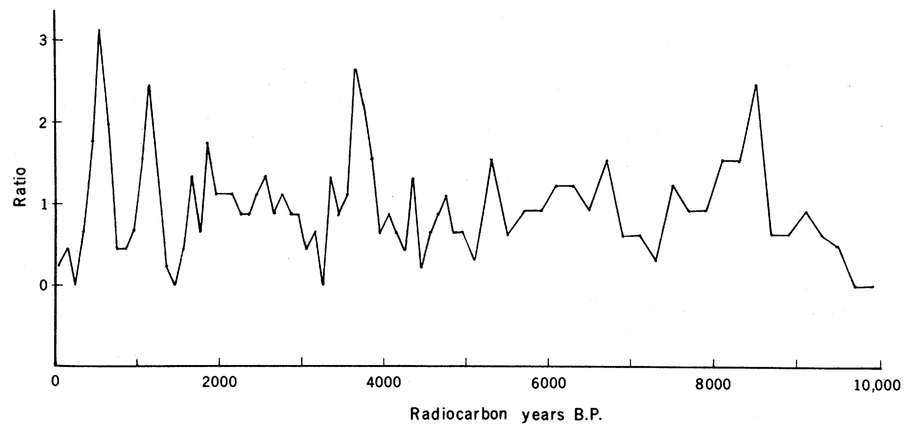

Fig. 3. Ratio of observed to expected number of dated volcanic events per century or two centuries during the past 10,000 years.

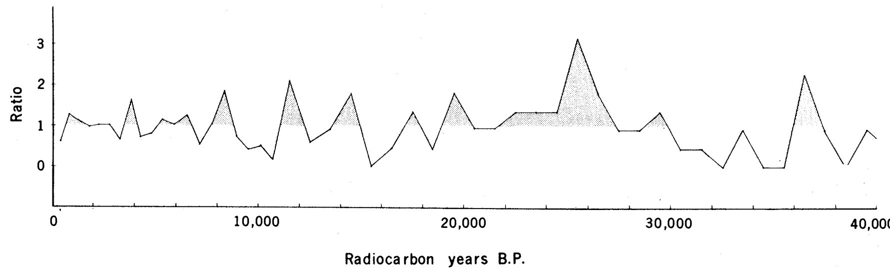

Fig. 4. Ratio of observed to expected number of dated volcanic events per 500 or 1,000 years during the past 40,000 years.

Late Pleistocene Volcanic Activity

Plotting the ratio of observed to expected volcanic event dates at 500-year intervals back to 12,000 B.P. and at 1,000-year intervals from 12,000 to 40,000 B.P., we arrive at Fig. 4. The dates are too few to be definitive, but there appears to be a rough correspondence of low volcanic activity with the Farmdalian interval (to about 27,000 B.P.) and of enhanced activity especially to the onset of the Woodfordian substage (after 27,000 B.P.). The Mankato (~ 14,000 B.P.) and Valders (~ 11,500 B.P.) substages are particularly marked, as is the quiet period (9,000 to 10,500 B.P.) associated with the rapid retreat of the continental glacier following the Valders. Further evidence that massive volcanic eruptions are associated with glacial stages and the cooling episodes during the Pleistocene can be found in Kennett and Thunell (*16*) and Bray (*17*).

One might infer from Fig. 4 a tendency toward a roughly 3000-year periodicity, especially in the last 20,000 years, in the level of Northern Hemisphere volcanic activity. However, much more investigation would be necessary to establish its reality, especially in view of the inherent biases in the data set.

Summary

It has been recognized for some years that there are multiple causes of climatic variation. On a long time scale there is growing recognition of the importance of the earth-sun orbital parameters first elucidated by Milankovich. At the short end of the scale a variety of factors, ranging from sunspots to internal feedback mechanisms, are under investigation. The analysis in this article suggests that variations in hemispheric and perhaps world levels of volcanic activity might be important on the scale of several years to several millennia. More investigation of the mechanisms that might provide some predictive capability is indicated, if the relations suggested here hold up under closer scrutiny.

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18. We thank K. Hirschboeck for compiling the historical volcanic eruption record and R. Roscoe for the spectral analysis of that record.

Boll Weevil Eradication

John H. Perkins

Summary. Some representatives of the cotton industry and of the entomological profession advocate efforts to eradicate the boll weevil. This coalition originated in 1958 from a complex of socioeconomic changes in cotton production and scientific developments in entomology. The results of a pilot eradication experiment (1971 to 1973) were controversial, and the debate was inhibited by social pressures upon the entomological profession. Substantial conceptual difficulties also attend evaluations of eradication experiments. A new trial eradication program is under way. If its evaluation is not to be warped by problems similar to the earlier ones, both the social and scientific aspects of eradication must be recognized and steps must be taken to ensure a full and open debate.

The boll weevil (*Anthonomus grandis* Boheman) (Fig. 1) has been a serious pest in U.S. cotton production since 1892 (*1*). Today it is a key pest in more than half of the U.S. cotton acreage and causes an estimated 8 percent loss of yield (*2*). Cotton producers spend an additional $50 million per year for insecticides (*3*). Environmental contamination from such efforts is high as an estimated 30 percent of all insecticides used in American agriculture is directed toward the boll weevil (*4*, p. 5).

Cotton growers have relied heavily on synthetic, organic insecticides to controll boll weevils since the late 1940's. Toxaphene and methyl parathion have received particularly high use as did toxaphene plus DDT until DDT was banned in 1972 (*3*, p. 2; *5*, *6*). Boll weevils developed resistance to the chlorinated hydrocarbon insecticides, beginning in 1954 (*7*), and entomologists fear it may develop resistance to organophosphates such as methyl parathion. Insecticides directed against the boll weevil also induced outbreaks of secondary pests, notably the bollworm [*Heliothis zea* (Boddie)] and the tobacco budworm [*Heliothis virescens* (Fabricius)]. *Heliothis* spp. in turn have developed resistance against insecticides that renders them difficult or impossible to control with chemicals (*6*).

Resistance, outbreaks of secondary pests, and environmental hazards induced entomologists and cotton producers to seek new control strategies for the boll weevil. One, insect pest management, aims to keep boll weevils at or below the economic threshold (the population density above which the returns from increased yields exceed the costs to suppress) without inducing secondary pests (*6*). Such schemes are now in use in some areas, particularly the lower Rio Grande Valley of Texas (*8*). A second strategy is to eradicate the insect from the United States (*9*). The U.S. Department of Agriculture (USDA) in conjunction with the cotton industry and the states of Virginia, North Carolina, and South Carolina launched a 3-year trial boll weevil eradication program (TBWEP) in 1978 (Fig. 2). Its objective is to determine whether technology is currently available to eradicate the boll weevil from the United States. A judgment that eradication technology is available could lead to the launching of a multimillion-dollar national eradication program. The technology being tested in TBWEP will be compared with an insect pest management strategy deployed in the optimum insect pest management trial (OIPMT) running concurrently in Panola County, Mississippi (*10*).

Difficult policy questions are raised by the simultaneous existence of two alternative and mutually exclusive control strategies: (i) What is the effectiveness of each? (ii) Does either require or deserve additional research? (iii) Are research needs for the two interchangeable? (iv) How should priorities be set on additional research needs? (v) If both strategies are successful, which (if either) should be implemented and how? (vi) Successful new control strategies for boll weevil might alter regional patterns of cotton production (*11*). What steps would be needed to alleviate possible socioeconomic distress?

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